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# OVERVIEW OF HYPERSONIC/TRANSATMOSPHERIC VEHICLE PROPULSION TECHNOLOGY

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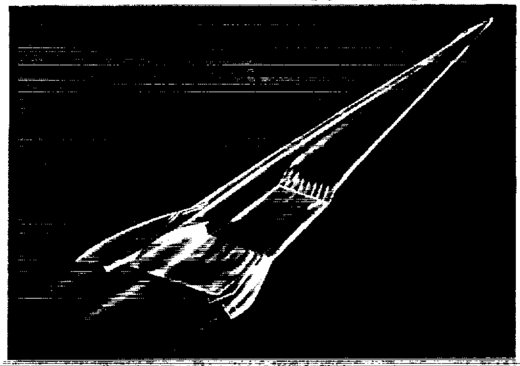
Significant progress is being made in attaining many of the enabling technologies critical to the development of future hypersonic vehicles such as the single-stage-to-orbit National Aerospace Plane (NASP) X-30 vehicle and others. In the NASP program, we have safely produced and transferred slush hydrogen in modestly large quantities. Inlet testing has demonstrated that a high-performance configuration can be developed, and configurations have been developed that reduce cross-talk between engine modules and improve unstart margins. Tests of a hydrogen-fueled ramjet engine model have been conducted to investigate engine operability and dynamics, and future tests are planned to demonstrate a closed-loop engine control system. Nozzle tests have identified large transonic-drag losses in the nozzle, which were then reduced significantly through the use of external burning. In other research areas, such as engine seals, advanced materials, and para-to-ortho hydrogen conversion, promising concepts have been identified and continuing efforts are adding to these technologies. In the Generic Hypersonics program we are gaining an improved understanding of the physics of inlets, combustors, and nozzles and are developing advanced materials and computational codes that predict the characteristics of both reacting flows and metal-matrix composite structures. The High-Mach Turbine-Engine (HiMaTE) component technology program has identified the turboramjet and the air-turboramjet as the most promising combined-cycle engines for more detailed assessment. Efforts are continuing to define critical components for development and testing to demonstrate technology readiness and to establish cycle feasibility. Studies are being conducted to assess the potential benefit of using these combined-cycle engines to power the first stage of two-stage-to-orbit (TSTO) vehicles and other hypersonic vehicles.

## Hypersonic/Transatmospheric Vehicle Propulsion Technology

### Focused Technology Programs



- National Aerospace Plane
- Generic Hypersonics

**Fundamental R&T**

- Inlets
- Nozzles/External burning
- Engines/Controls
- Slush hydrogen
- Para-to-ortho hydrogen
- Sensors
- Seals
- Materials
- Analyses codes
  - Fluid dynamics
  - Structures

- High-Mach Turbine Engine (HiMaTE) (Joint NASA-Air Force)
  - Cycle studies
  - Component technology demonstrations
  - Possible combined-cycle demonstration

**System studies**

- TSTO vehicles
- Advanced missiles
- Mach-4 to -6 aircraft

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The Hypersonic/Transatmospheric Vehicle (TAV) propulsion technology effort at NASA Lewis Research Center encompasses three focused technology programs: the National Aerospace Plane (NASP) with its single-stage-to-orbit (SSTO) X-30 vehicle, NASA's Generic Hypersonics, and the joint NASA-Air Force High-Mach Turbine-Engine (HiMaTE) component technology program. The NASP Program focuses primarily on scramjet propulsion systems which are highly integrated with SSTO vehicles. NASP must rely on near-term technologies because of an early first flight. Generic Hypersonics, on the other hand, focuses on the development of fundamental research and technology required for the design of future air-breathing propulsion systems to power accelerating and other hypersonic vehicles. This program focuses on longer-term technologies. The HiMaTE component technology program focuses on turbomachinery-based, air-breathing propulsion systems for transatmospheric and hypersonic vehicles operating in the Mach 4 to 6 flight speed range. This program will result in the development of nearer-term technologies which can enable nearer-term air-breathing propulsion vehicles.

# Hypersonic/Transatmospheric Vehicle PropulsionTechnology
(concluded)

## Goals

- Provide enabling hypersonic technology for future hypersonic/transatmospheric flight vehicles
  - Place emphasis on air-breathing propulsion
  - Blend technologies from aeronautics and space propulsion

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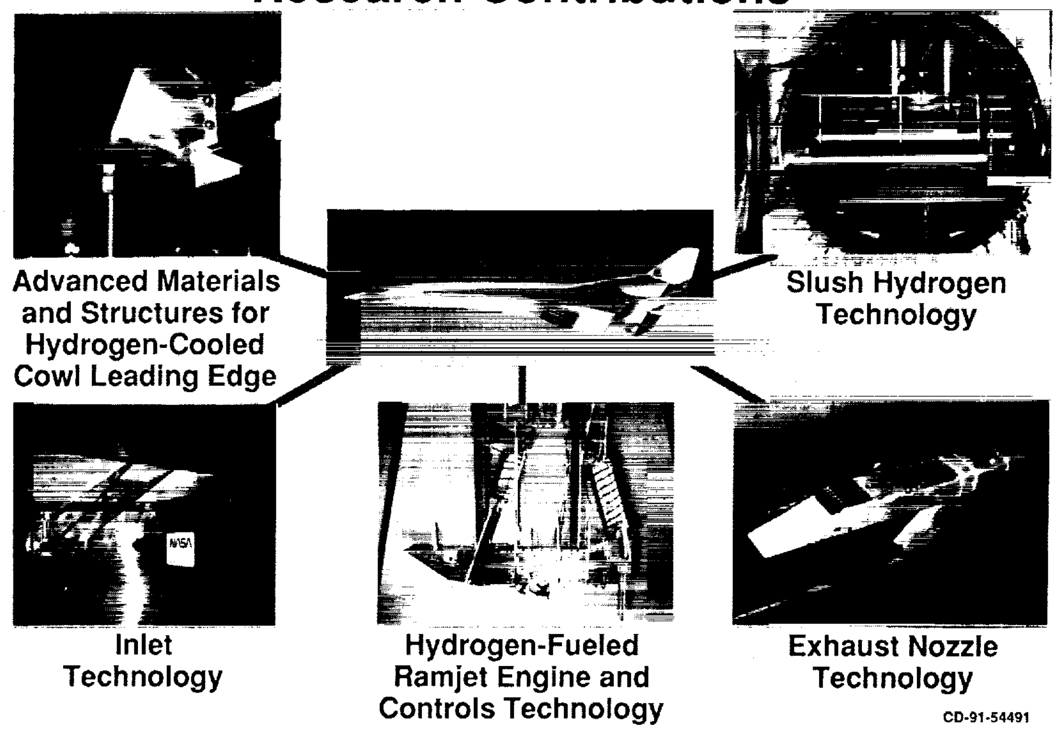
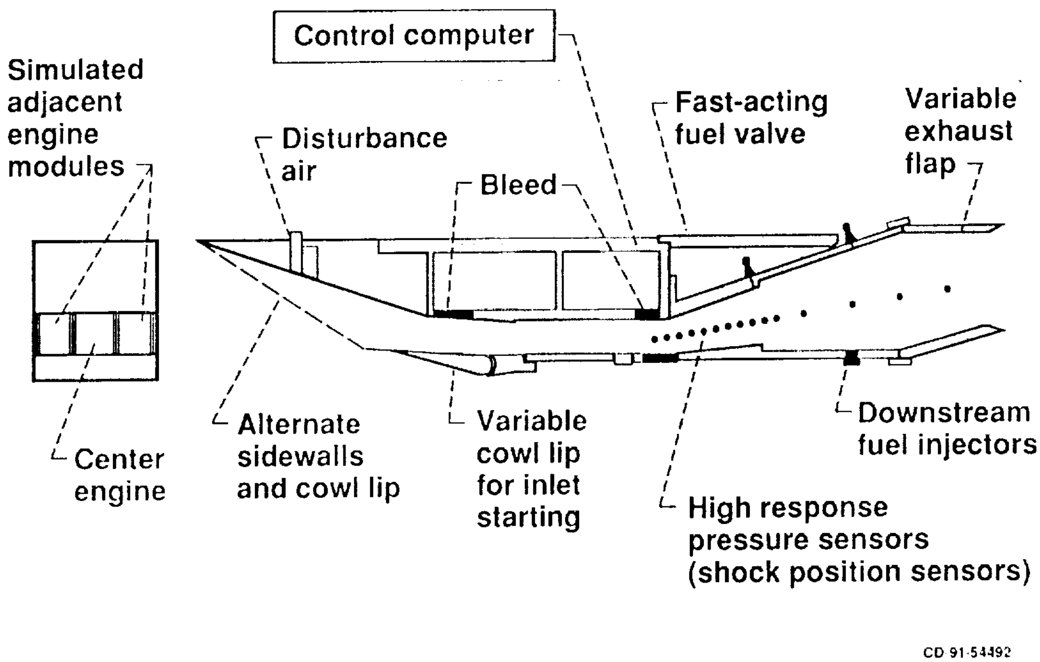
# Hypersonic/Transatmospheric Vehicle Research Contributions




Currently the NASA Lewis Research Center is conducting propulsion system research which will be used to develop the National Aerospace Plane and other transatmospheric and hypersonic vehicles. Significant contributions are being made in the following areas: advanced materials and structures for hydrogen-cooled engine components and seals; wind tunnel tests for inlet studies, operational characteristics of hydrogen-fueled ramjets, and exhaust nozzles; and slush-hydrogen fuel production, use, storage, and handling. Lewis is also supporting NASP by developing advanced para-to-ortho hydrogen conversion catalysts that will enhance the cooling capability of hydrogen at cryogenic temperatures. Finally, analytical codes are being developed and used extensively to predict the high-speed internal flows in components and engine systems, the structural characteristics of metal-matrix composites, and the characteristics of slush hydrogen in fuel and storage tanks.

## Modified Government Baseline Engine For NASP




A hydrogen-fueled ramjet engine model, referred to as the NASP government baseline engine, was recently modified extensively to investigate engine operability and control. The model now incorporates all of the major NASP engine features as well as several design options and special instrumentation. For simplicity and reduced cost, the subscale engine model was built using heat-sink construction, which limits the duration of tests. Some of the major engine features include bleeds in the inlet and throat regions; a variable cowl lip for inlet starting, inlet flow passages on either side of the center engine to simulate adjacent engine modules and study module-to-module interactions; alternate sidewall configurations designed to reduce or eliminate adverse engine interactions; and the capability to induce high-frequency disturbances of the inlet and fuel flows for dynamic tests. A 6-month test of this engine model was conducted by Lewis at the General Applied Science Laboratories (GASL) to investigate engine operability, dynamics, and performance at a Mach-3.5 flight condition.

## Modified Government Baseline Engine Test Results Summary

- Variable cowl lip permits inlet starting and provides good performance
- Combustor ignition achieved with spark igniter (silane not required)
- Representative combustor operating region defined for dynamic tests
  - High equivalence ratios reached without inlet unstart
- Engine relight and inlet restart sequences demonstrated
- Engine dynamic response to inlet and fuel flow disturbances measured for comparison to analysis and input to control design

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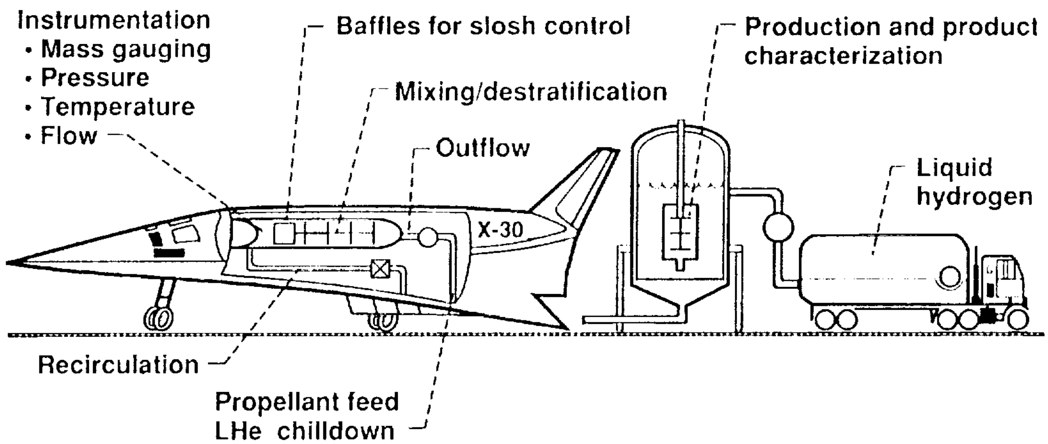
Improved understanding of engine operability and other significant results was obtained in recently completed tests of the engine at GASL. We used these results to define an inlet configuration which has both excellent starting-restarting characteristics and high performance levels. During the combustor testing, ignition was achieved by using only a spark ignitor, and stable combustor operation was achieved at the desired high-pressure conditions without unstarting the inlet (the equivalence ratio was limited to about 0.8 by facility interactions). Unique operating procedures, which included both an inlet and combustor restart sequence, were developed to both start and relight the engine. The effects of an adjacent engine module unstart on engine operation were experimentally evaluated at various operating conditions, and configurations were developed to reduce cross-talk between engine modules and to improve the unstart margin. The engine dynamic response to inlet and fuel flow disturbances was measured for comparison to the analyses. This dynamic response information is now being used to modify the design of a control system which will provide closed-loop engine control in an upcoming test in the Lewis Propulsion Systems Laboratories (PSL). These test results are helping designers to develop the NASP engine flow path and control system.

# Slush-Hydrogen Technology

**Technology Advances Needed:** **Ground Handling**




Benefits of slush hydrogen
- 16 % increase in density
- 18 % increase in heat-sink capacity
- Reduced tank pressure (conformal tanks)

→ Decreased aircraft volume and drag → 15 to 35% lower takeoff weight

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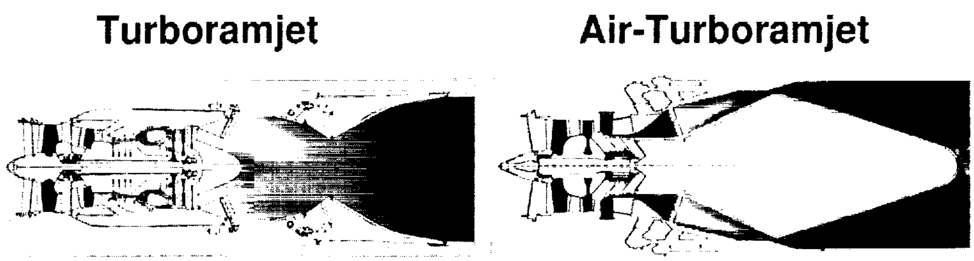
Slush hydrogen as a fuel is being investigated to support the NASP program. A viable slush-hydrogen fuel would contain a mixture of approximately 50 percent solid hydrogen suspended in the liquid hydrogen. This mixture would provide a 16-percent increase in propellant density and an 18-percent increase in heat-sink capacity, which translates directly to decreased vehicle volume and drag. The resulting major reduction in vehicle gross takeoff weight is from 15 to 35 percent, depending on whether or not warm hydrogen is recirculated to the tank. The critical slush-hydrogen technologies are related to making, storing, recirculating, mixing, transferring, measuring, and predicting characteristics. We are investigating these technologies at our K-Site facility at Plum Brook Station. Recently, a slush mixture with a solid-to-liquid fraction of 60 to 65 percent was produced by the freeze-thaw method, successfully transferred for the first time to a 500-gallon research tank, and subsequently expelled from the tank. These tests clearly demonstrated that slush hydrogen can be produced and safely distributed in modest quantities according to the NASP X-30 requirements. In conjunction with the testing, analytical codes are being developed to help researchers understand and predict the flow characteristics and fluid properties inside fuel and storage tanks at various operating conditions.

## HiMaTe Component Technology Propulsion Program




**Objectives:**

- Investigate propulsion advantages of combining the best air-breathing and rocket technologies in an engine capable of operating over a range of flight conditions from Mach 0 to 6
- Conduct critical component demonstrations to establish cycle feasibility and technology readiness

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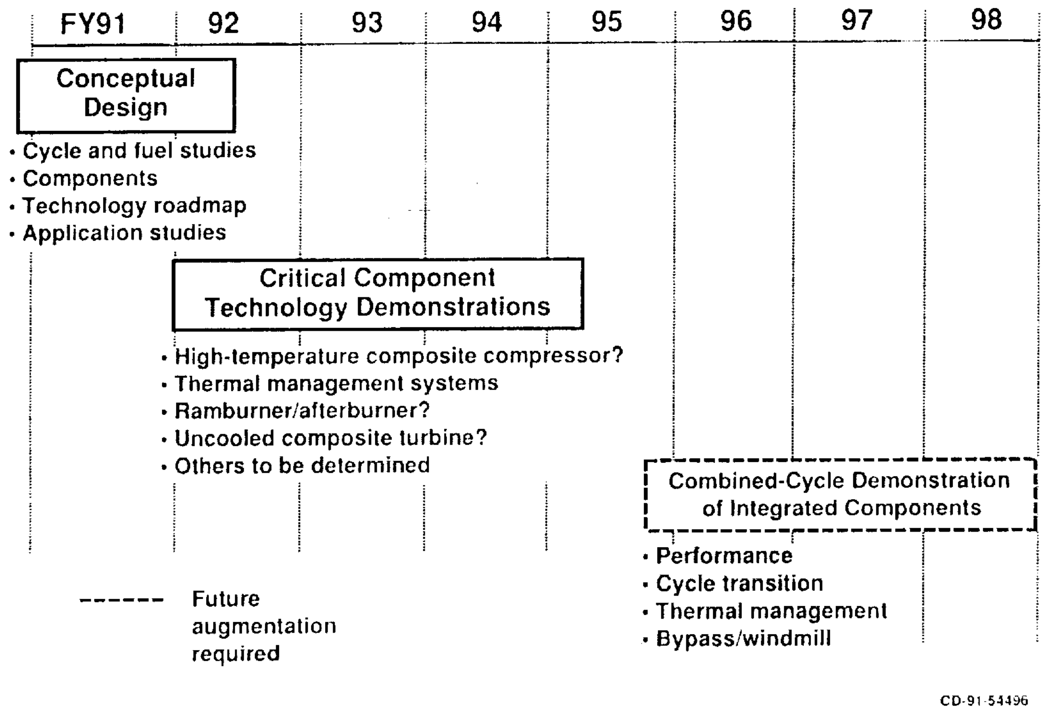
The HiMaTE component technology program attempts to blend the best features of both air-breathing and rocket propulsion technologies in one combined-cycle engine system capable of operating over the complete flight speed range from Mach 0 to 6. Future hypersonic vehicles will require a propulsion system which provides both high performance and high thrust-to-weight ratios while operating in a very severe thermal environment. High-performance turbomachinery will be pushed to as high a speed condition as possible (to about Mach 3.5+). Using rocket technology, a gas generator will be considered to power the turbine; thus, operations at high-speed conditions will not be limited by the hot section of the engine because of high inlet air temperatures. Using a gas generator will also permit a reduced turbine size, which will significantly increase the thrust-to-weight ratio of the engine. At the higher speed conditions (from Mach 4 to 6), a ramjet cycle will be used for high performance, and regenerative fuel cooling will be used to enable adequate thermal management without compromising performance. The turboramjet and airturboramjet have been identified as the most promising combined-cycle engines for more detailed assessment. At the higher speed conditions, these engine systems, respectively, bypass the flow around the turbomachinery and windmill the turbomachinery.

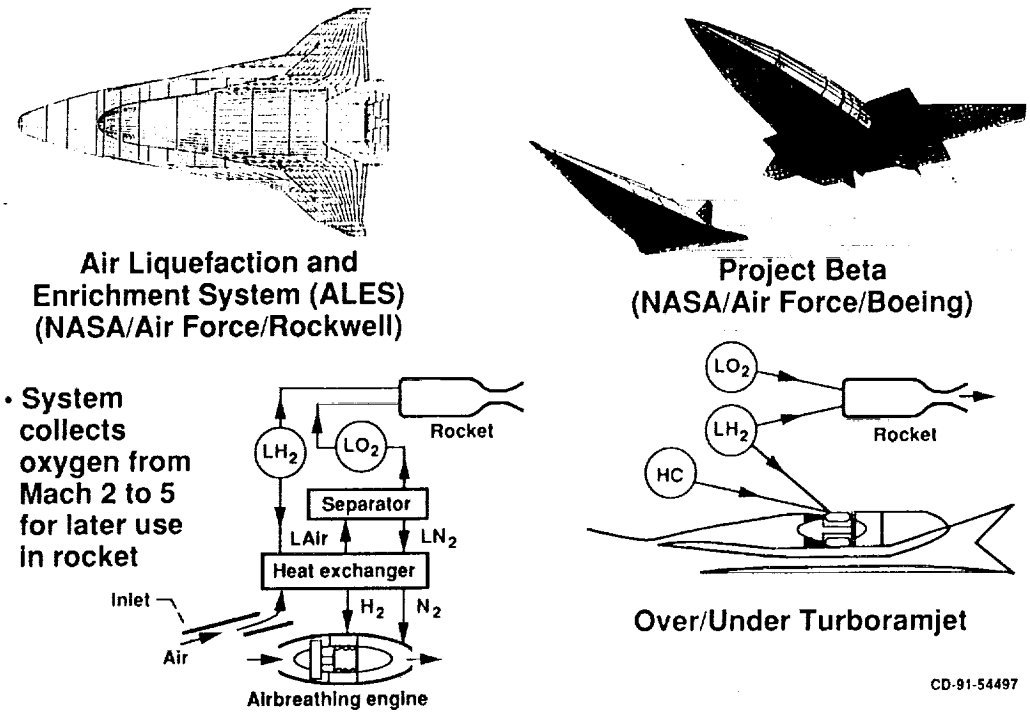
## HiMaTE Component Technology Program (Joint NASA–Air Force Program)




General Electric Company and Pratt & Whitney are the two HiMaTE prime contractors working on the turboramjet and air-turboramjet combined-cycle propulsion systems, respectively. Currently, they are conducting conceptual design studies to assess the cycles, fuels, and potential benefits of these propulsion systems in various applications. Also engines and individual components are being designed and the component technology needs assessed relative to the state-of-the-art. The assessment includes choosing materials and laying out technology roadmaps to validate component technologies and cycles. Shortly, the contractors in concert with NASA and the Air Force will select unique, critical components and identify those efforts required to develop and demonstrate component technology readiness. As yet, all of these critical components have not been identified, but a thermal management system, which is required to operate in the severe thermal flight environment of Mach 4 to 6, will be one of the required unique elements. Other critical component technologies being considered are a high-temperature composite compressor, a ramburner/afterburner, and an uncooled composite turbine. After the selected critical components have been demonstrated, a funding augmentation will be advocated for conducting a combined-cycle demonstration in the Lewis PSL facility. This demonstration of the components integrated into a system would be used to verify performance levels, cycle transition, thermal management, and hot gas bypass or windmilling of the turbomachinery.

## Transatmospheric Vehicle Studies

**Objective: demonstrate potential of utilizing turbomachinery-based propulsion concepts in transatmospheric vehicles**




Transatmospheric vehicles (TAV's) and other military vehicles such as a multirole Mach-4 to -6 aircraft and advanced missiles are being studied to evaluate the potential benefits from using turbomachinery-based air-breathing propulsion systems in these applications and to define the propulsion requirements. Two studies are being conducted on two-stage TAV's to evaluate the potential for using low risk air-breathing propulsion to power the first-stage booster and rockets to power the orbiter. In these two-stage-to-orbit (TSTO) vehicle applications, the air-breathing propulsion system weight for the booster is not as critical a driving parameter as it is in the single-stage-to-orbit (SSTO) vehicles because the booster is only accelerated to Mach 5 or 6. The first study, Project Beta is a joint effort with the Air Force and Boeing to evaluate a two-stage vehicle with a bottom-mounted orbiter capable of putting a 10 000-pound payload into polar orbit. Current study vehicles use near-term materials and a hydrocarbon (HC)- and hydrogen-fueled over-under turboramjet engine to power the booster vehicle to Mach 6, followed by a staging of the rocket-powered orbiter. The second study uses an air-liquefaction and enrichment system (ALES). This study is a joint effort with the Air Force and Rockwell to evaluate a two-stage vehicle with a top-mounted orbiter. This vehicle is also capable of putting a 10 000-pound payload into polar orbit. Current study vehicles use near-term materials and a hydrogen fueled air-turboramjet propulsion system for powering the booster up to about Mach 5, where the rocket-powered orbiter is then launched. During first-stage operation of the air-breathing propulsion system, large quantities (at least 30 percent) of air are liquified, separated, and stored in the orbiter for later use in the second-stage rocket. These two-stage-to-orbit vehicles using air-breathing propulsion for the first stage offer a lower risk approach which still presents major engineering challenges but does not require the invention of a major new propulsion system.

# Summary

These focused propulsion technology efforts will

- Extend efficient air-breathing engine operation to Mach 6 and provide high thrust-to-weight engines
- Enable the development of cruise vehicles capable of higher speeds (Mach 4 to 6)
- Enable development of two-stage-to-orbit vehicles with low risk air-breathing propulsion

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